The effect of blowing and suction on characteristics of a viscous sublayer is studied theoretically and experimentally.

Despite the element of arbitrariness in subdividing turbulent boundary-layer flow into a viscous sublayer and a turbulent core, such an approach is widely used within the framework of two-layer models of turbulence. To determine the effect of external perturbing factors (pressure gradient, blowing, suction) on characteristics of the viscous sublayer, investigators have proposed several hypotheses based on fixing various parameters at the boundary of the viscous sublayer: the Reynolds numbers \( \text{Re}_1 \) [1] and \( \text{Re}_2 \) [2], and the velocity \( u_+ \) [1, 3, 4]. The hypotheses advanced in [5, 6] are equivalent to the condition \( \text{Re}_2 = \text{const} \) [2]. In analyzing the effect of transverse mass flow on the viscous layer in [3, 7], it was held that suction must increase and blowing must decrease the stability of the laminar section near the wall. In connection with this assertion, the Reynolds number \( \text{Re}_1 \) should increase with suction and decrease with blowing. Such a character of dependence of the Reynolds number \( \text{Re}_1 \) on the rate of transverse mass flow \( \text{Re}_v \) is regarded in these studies as confirmation of the correctness of the chosen hypothesis for calculation of the characteristics of the viscous sublayer. To check the validity of different hypotheses, the present work theoretically and experimentally studies the effect of suction and blowing on the stability criterion \( \text{Re}_1 \) and other characteristics of the viscous sublayer.

1. As a model of flow in the viscous sublayer, we will use generalized Couette flow with a constant transverse velocity. The profile of axial velocity is described by the expression

\[
\overline{u} = \frac{\exp(\text{Re}_e y) - 1}{\exp(\text{Re}_e) - 1}
\]  

or, in universal coordinates, \( u_+ = \left[ \exp(\sqrt{V_+ y_+}) - 1 \right] / V_+ \).

The parameters of the viscous sublayer \( \delta \) and \( u_\delta \) were found with the assumption that the number \( \text{Re}_1 \) is the maximum possible value of the Reynolds number at which monotonic damping of random perturbations can occur. Thus, \( \text{Re}_1 \) coincides with the critical Reynolds number \( \text{Re}_{1\text{cr}} \), which can be determined from an energy analysis of flow stability [8].

The presence of transverse velocity in the flow does not affect the form of the equation for perturbations, which coincides with the usual Orr equation for plane-parallel flow [9]:

\[
\left( \frac{d^2}{dy^2} - k^2 \right) \left[ \frac{1}{\overline{u}^2} \left( \frac{d\overline{u}}{dy} - k \overline{u} \right)^2 \varphi + i k \text{Re}_1 \cos \theta \left( \varphi' + \frac{\overline{u}'}{2\overline{u}'} \varphi \right) \right] + \frac{k^2 \text{Re}_1^2 \sin^2 \theta \overline{u} \varphi}{4} = 0. 
\]  

The boundary conditions for Eq. (2) were assigned in the form

\[
\varphi = \varphi' = \varphi^{1V} = 2k^2 \varphi^r = 0 \text{ at } \overline{y} = 0.1.
\]  

The eigenvalue problem (2)-(3) was solved by the method of differential trial run [9]. The results of calculation of the critical energy Reynolds number \( \text{Re}_{1\text{cr}} \) in relation to the value of the blowing or suction parameter \( \text{Re}_v \) are shown in Fig. 1. Analysis of Eq. (2) with
allowance for the velocity distribution (1) shows that the effect of transverse mass flow on stability proves to be symmetrical relative to the sign of $Re_v$. It can be seen from Fig. 1 that the value of $Re_{e1cr}$ increases with both blowing and suction.

Using the relation obtained $Re_{e1cr}(Re_v)$ and the relations $Re_{e1cr} = u_{\delta+}\delta_+$, $Re_v = V_4\delta_+$, $u_{\delta+} = [\exp(V_4\delta_+) - 1]/V_4$, we determined the effect of the parameter $V_4\delta_+$ on the relative values of the Reynolds number of the viscous sublayer $Re_{e1} = Re_1/Re_{e0}$ and the thickness of the sublayer $\delta_+ = \delta_+ / \delta_{+0}$ (curves 1 in Fig. 2a and b), where $Re_{e0}$ and $\delta_{+0}$ are the corresponding values on an impermeable surface.

Figure 2 also shows calculated curves of $Re_{e1}$ and $\delta_+$ obtained by using the hypothesis $Re_1 = const$ (curves 2), $Re_2 = const$ (3), and $u_{\delta+} = const$ (4). It should be noted that, in the chosen variables, the relations $Re_{e1}(V_4\delta_{+0})$ and $\delta_+(V_4\delta_{+0})$ are not affected by the specific value of $\delta_{+0}$, which is different in works by different authors. It can be seen from the figure that, despite the difference in the behavior of the dependence of the Reynolds number of the viscous sublayer on the intensity of the transverse mass flow, all of the hypotheses used give qualitatively the same results for the relative thickness of the viscous sublayer in blowing and lead to a decrease in $\delta_+$. In the case of suction, it follows from all four hypotheses that $\delta_+$ should increase. However, the hypothesis $Re_2 = const$ is valid at $|V_4\delta_{+0}| < 0.733$, while the hypothesis $u_{\delta+} = const$ is valid at $|V_4\delta_{+0}| < 1$; given large values of the parameter $|V_4\delta_{+0}|$ neither hypothesis gives the actual value for the thickness of the viscous sublayer.

2. The experimental study of the turbulent boundary layer was conducted on a gasdynamic unit equipped with a hot-wire anemometer and an interferometer [10, 11]. The working section was a channel of square cross section. A plate with a porosity of $\approx 65-70\%$ was installed in the lower wall of the channel. The experiment was conducted under isothermal conditions. The longitudinal pressure gradient created in the external flow by the blowing was eliminated by regulating the position of the flexible upper wall. The velocity distribution in the boundary layer was measured with the anemometer, and we took the effect of the wall on the anemometer readings in the boundary region into account.

The thickness of the viscous sublayer was determined as the distance from the wall at which the velocity distribution deviated 10% from exponential relation (1). As can be seen